BNH CRC: RESEARCH ADVISORY FORUM

17-18 November 2015

PROJECT B8: ENHANCING RESILIENCE OF CRITICAL ROAD STRUCTURES: BRIDGES, CULVERTS AND FLOOD WAYS UNDER NATURAL HAZARDS

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RMIT University

An Australian Government Initiative

OUTLINE

1) Project overview and program
2) Progress since the last RAF and to date
3) Numerical studies of flood-ways and bridges
   a) Flood
   b) Bushfire
   c) earthquake
4) Economic consequence assessment of flood events
5) Decision tree conceptualisation
6) Way forward
7) Questions / Comments

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HDR students

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- Mr. Albert (Yue) Zhang
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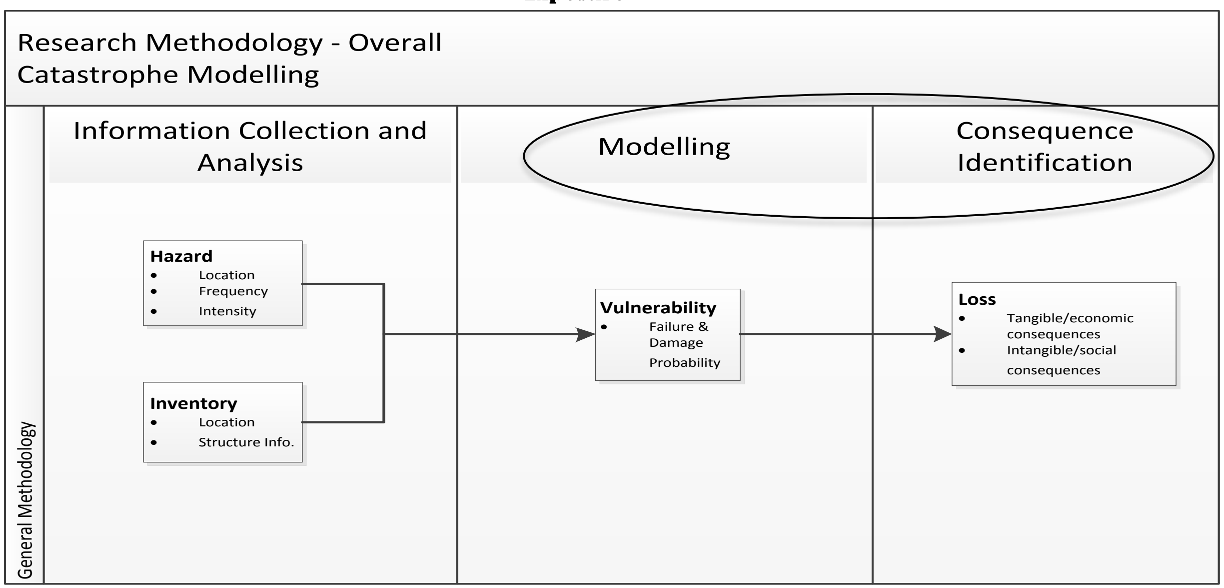
RESEARCH PROGRAM – STAGE 1 CURRENT PROJECT- METHODOLOGY



Quantitative Risk Assessment

$$R = H_z \times V_u \times C_q$$

STAGE 2 – SECOND PHASE OF THE 7 YEAR PROJECT

- Expand the outcomes to cover national road authorities and Local govt. interests

- Strengthening options – traditional and emerging techniques

- Optimised decision making on hardening of structures
  - What, where, when and how to strengthen structures
  - Non asset solutions

- Decision support software tool

MILESTONES - ON TRACK

- Failure of road structures under natural hazards – report 1
- Community impact of failure of road structures – Report 2
- Failure mechanisms and vulnerability modelling – Report 3
- Analysis of design standards – Report 4- in progress
- 3 Journal papers, 4 Conference papers
- Industry workshops

END USER ENGAGEMENT

- Workshop 1 - Lockyer Valley council, July 2014
- Workshop 2 - QTMR – to finalise the report 1, Nov. 2014
- Researchers spent a week in Lockyer Valley, Feb. 2015
- Workshop 3 - LVRC/QTMR – Report 2, March 2014
- Workshop 4 - VicRoads , April 2014
- Meeting with RMS NSW, July 2015
- Workshop 5 – Mini Symposium, Wider stakeholders, July 2015
- Presentation to Austroads Bridge Task Force, October 2015
- Presentation to RMS bridge conference 2 Dec. 2015

OUTCOMES TO DATE

- The methodology for evaluating vulnerability based on structural capacity established.
- Case studies of failure of bridges under natural hazards completed –methodology of analysis demonstrated
  - Flood – Lockyer Valley bridge case studies
  - Bushfire – Effect of fire on concrete bridges
  - Earthquakes – Lockyer Valley girder bridge under earthquake
- Methodology for establishing damage curves based on cost of recovery developed, with a floodway case study.
- Community resilience study conducted – researchers spent a week in Lockyer valley interviewing community
- A method to quantify the economic impact of failure of road structures established
- Decision tree is being developed to capture failure of structures and assist in decision making


MURPHY BRIDGE
m
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2



ANALYSIS OF ROAD STRUCTURES EXPOSED TO NATURAL HAZARDS

AN UPDATE: ADAPTATION REQUIREMENT IN VICTORIA

Table 6.10: Summary of Extreme Weather Related Risks to Infrastructure Types

	Consequences	Actions	Risk
Road Surfacing	Increased bushfires and flood may cause more frequent and more extensive damage to road surfaces	Investigate locations of vulnerability, possible protective measures, and flood flow management measures.	Important
Pavement Structure	Greater likelihood of widespread flooding could result in pavement damage and long term reduction of life for affected pavements.		
Drainage	Greater likelihood of widespread flooding could result in damage to drainage systems.		
Roadsides	Greater likelihood of bushfires, floods and storms will cause difficult conditions for many plants and animals.		
Structures	Greater likelihood of widespread flooding and storms could result in damage to structures and their footings.		
ITS/Electrical Assets	Greater reliance on traffic management systems to reduce congestion, ensure smooth traffic flow especially during extreme weather and emergency management events	Investigate potential locations for installation of uninterrupted power supply	Important
Operations	Greater pressure on emergency response resources.	No action required at this stage.	Important
	Decreased operational impacts of black ice and snow on roads	No action required	Positive

VicRoads Climate Change Risk Assessment, 2015

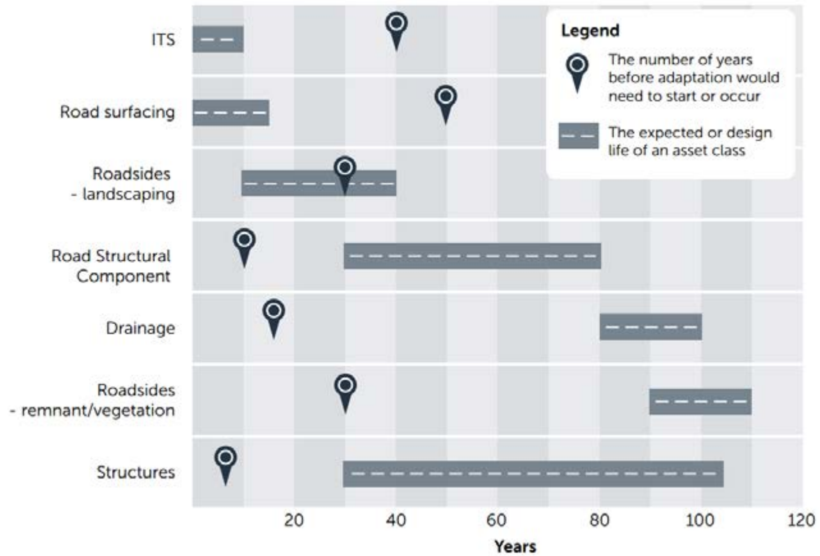


Figure 5.3 Design Life of Different VicRoads Asset Categories (Adapted from (UK Highways Agency, 2011))

MAJOR FAILURE MECHANISMS OF BRIDGES UNDER FLOOD

LOCKYER VALLEY
INSPECTION REPORT

Damage to abutment & headstock

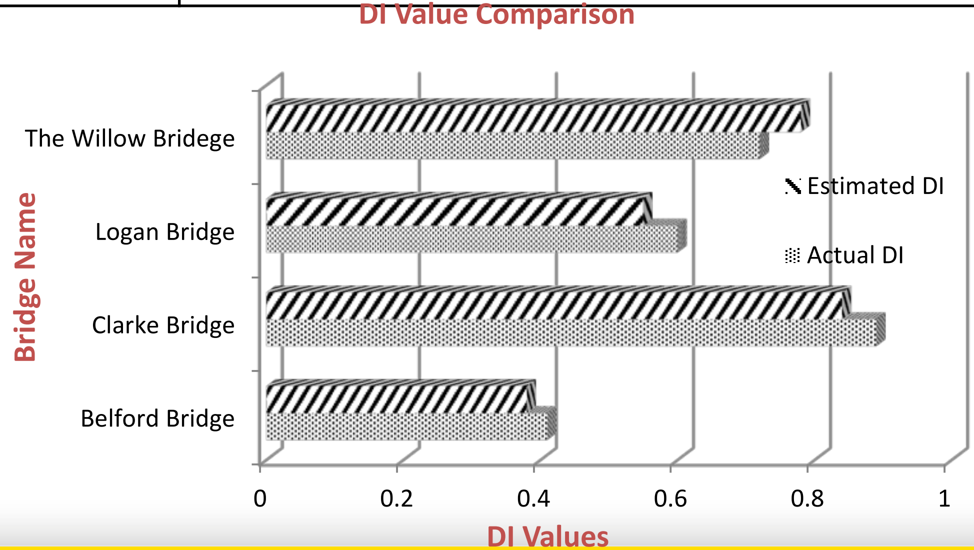
Completely washed away

Damage due to debris

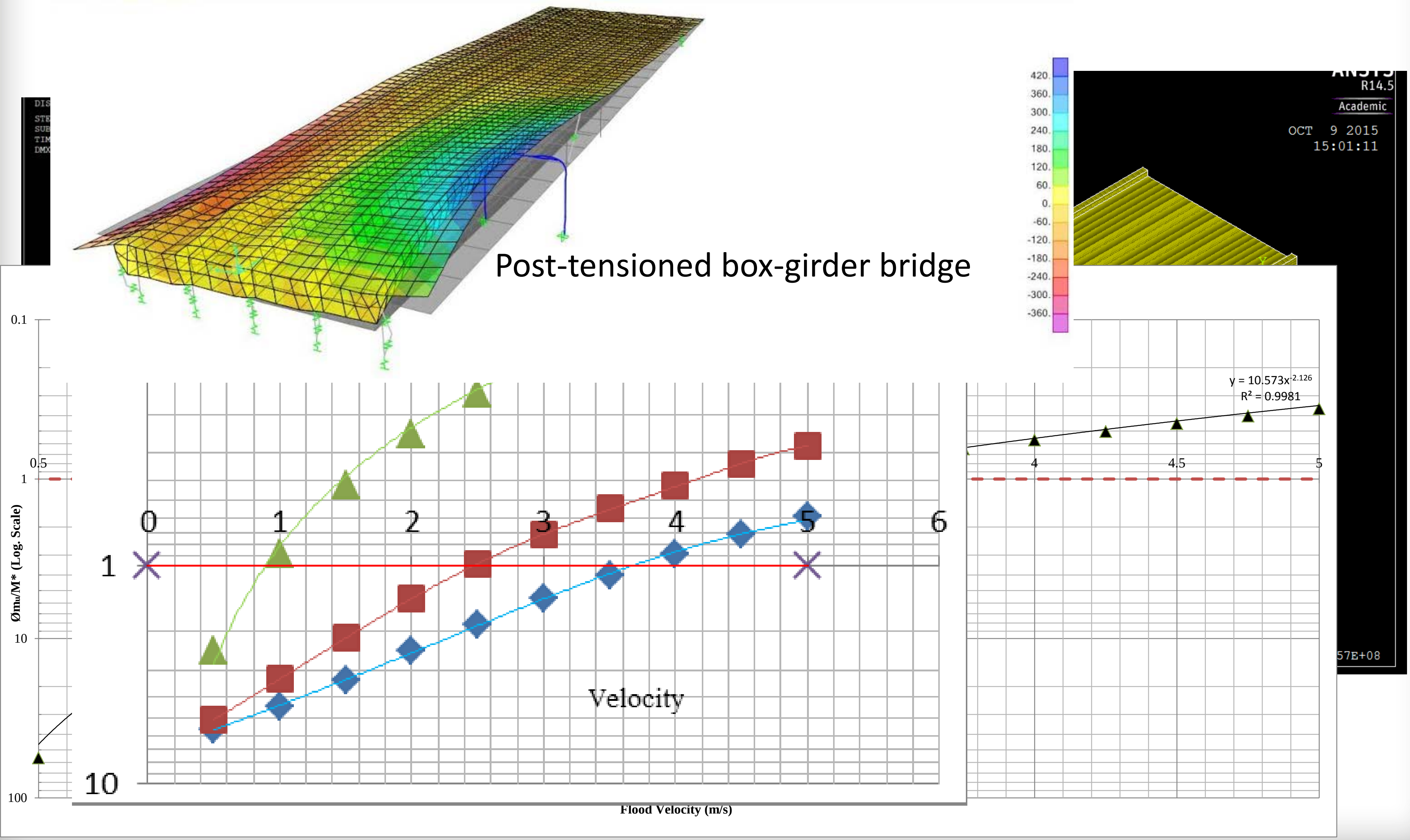
Damaged relieving slab

BRIDGES CASE STUDY

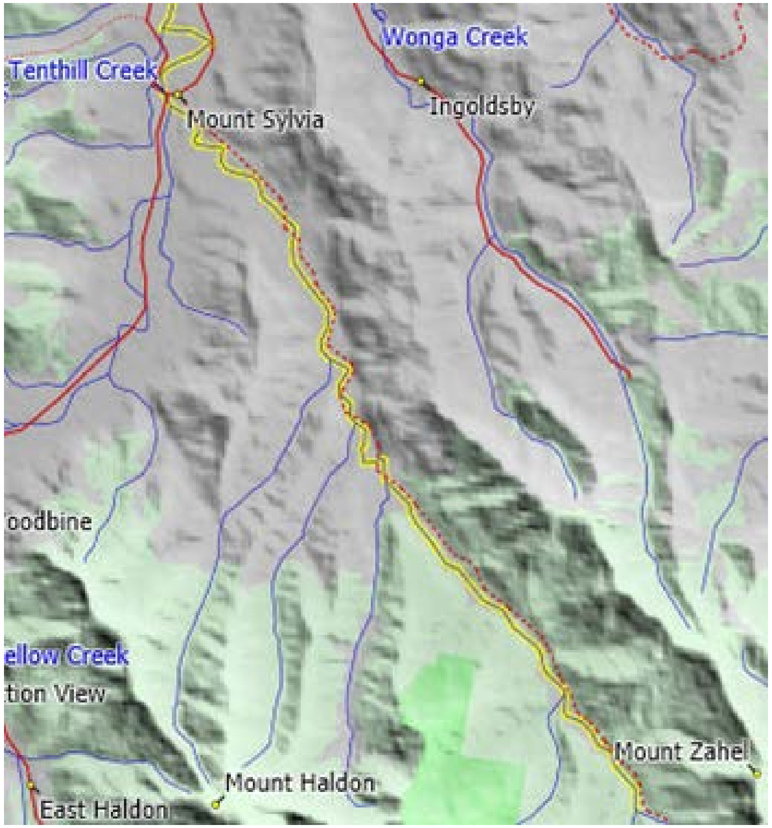
Bridge Name	Description of damage	Repair Cost (Aus$)	Estimated Replacement cost (Aus$)	DI
Belford Bridge	Scour and slumping of the southern upstream rock spill; Relieving slab and approach road kerb has been undermined; Substantial crack appeared in the downstream western wing wall	91,592	220,776	0.41
Clarke Bridge	Edge delineation had been damaged by debris; Some bank scour on the downstream side of the bridge	21,535	98903	0.21
Logan Bridge	Whole section of one approach has been damaged Significant scour of the eastern abutment Headstock has been undermined Cracks noted in the surfacing behind the eastern abutment	67,547	290,965	0.23
The Willows Bridge	Both approaches sustained substantial damage Bridge guardrails ripped off Upstream edge of the bridge broken	71,301	85,485	0.83



DAMAGE CURVES FOR BRIDGES UNDER FLOOD



FLOOD-WAYS MAJOR ISSUES



Tenthill Creek and Left Hand Branch rd


Washout

Cracking


Undermining


Damage to rock protection

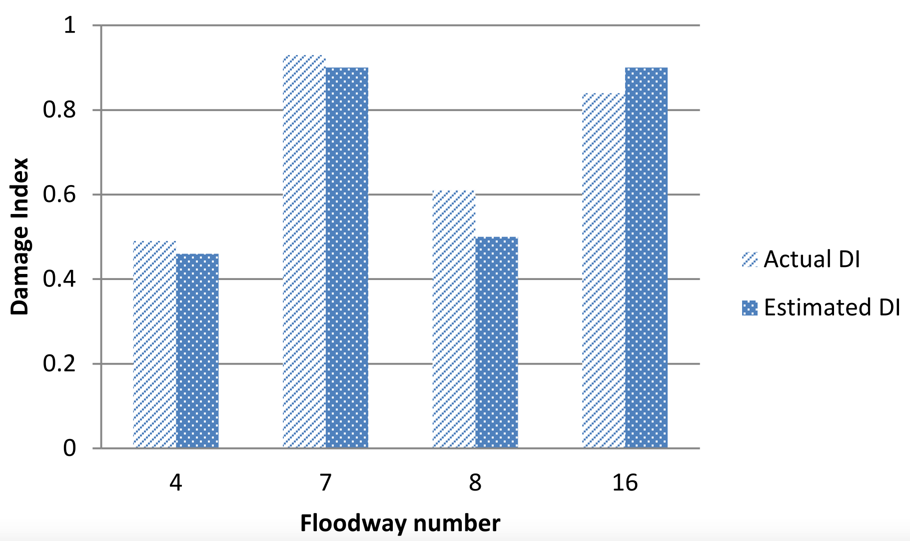

Culvert blocking


Scouring

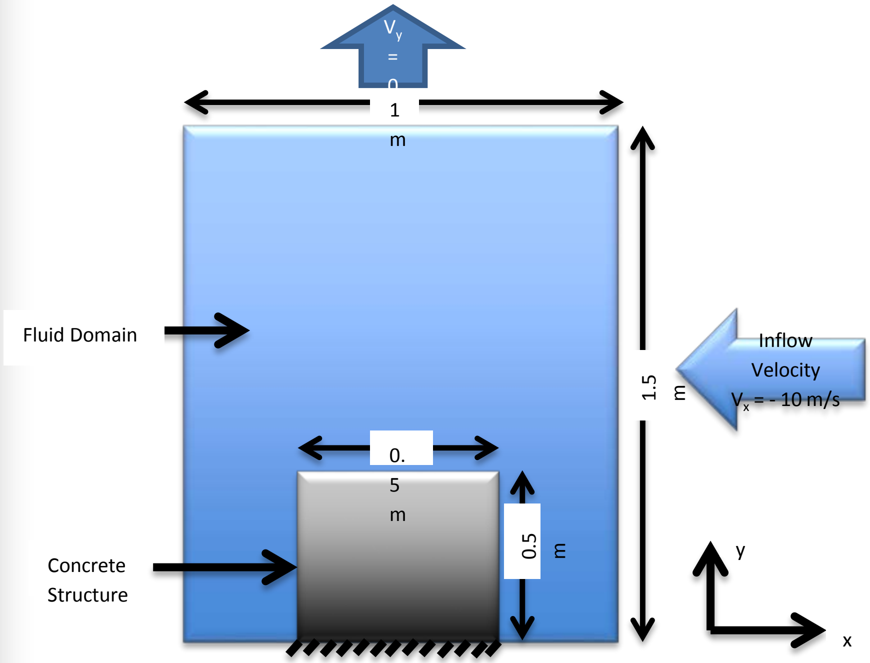
Common failure mechanisms

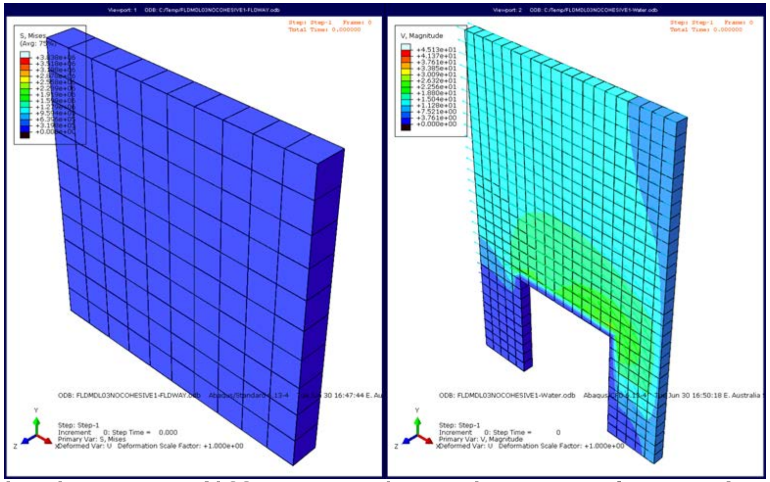
Estimated Damage Index Vs Actual Damage Index

ID No	Description of damage	Repair cost ($)	Estimated Replacement cost ($)	DI
4	Damage to rock protection, undermined and minor cracking	91,592	185,776	0.49
7	Seriously undermined and apron has been damaged	91,535	98,903	0.93
8	Cracking of floodway	67,547	109,965	0.61
16	seriously undermined and cracked	113,301	134,485	0.84

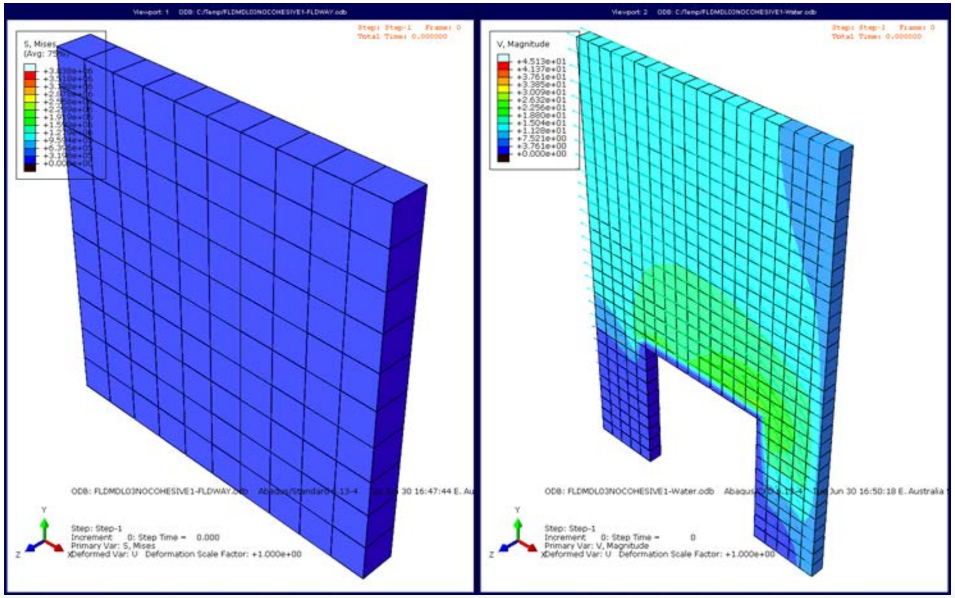


FLOOD-WAYS NUMERICAL STUDIES – IN PROGRESS





Stress variation at different time intervals and flow path and flow velocity variation



BRIDGES UNDER BUSHFIRE EXPOSURE/OTHER FIRE HAZARDS

Concrete bridge - Wright, W., et al., 2013


Steel bridge - Wright, W., et al., 2013


Timber bridge - Long Gully Bridge WA (7 News)

Reinforced concrete

- Concrete spalling
- Concrete cracking
- Concrete delamination
- Compressive strength reduction
- Steel reinforcement and prestressed strands strength reduction

Steel

- Steel distortion
- Deflection of steel elements
- Formation of plastic hinges
- Buckling (web buckling)
- Reduction of tensile and yield strength
- Post-fire steel toughness
- Steel pitting & flaking
- Paint and coating degradation

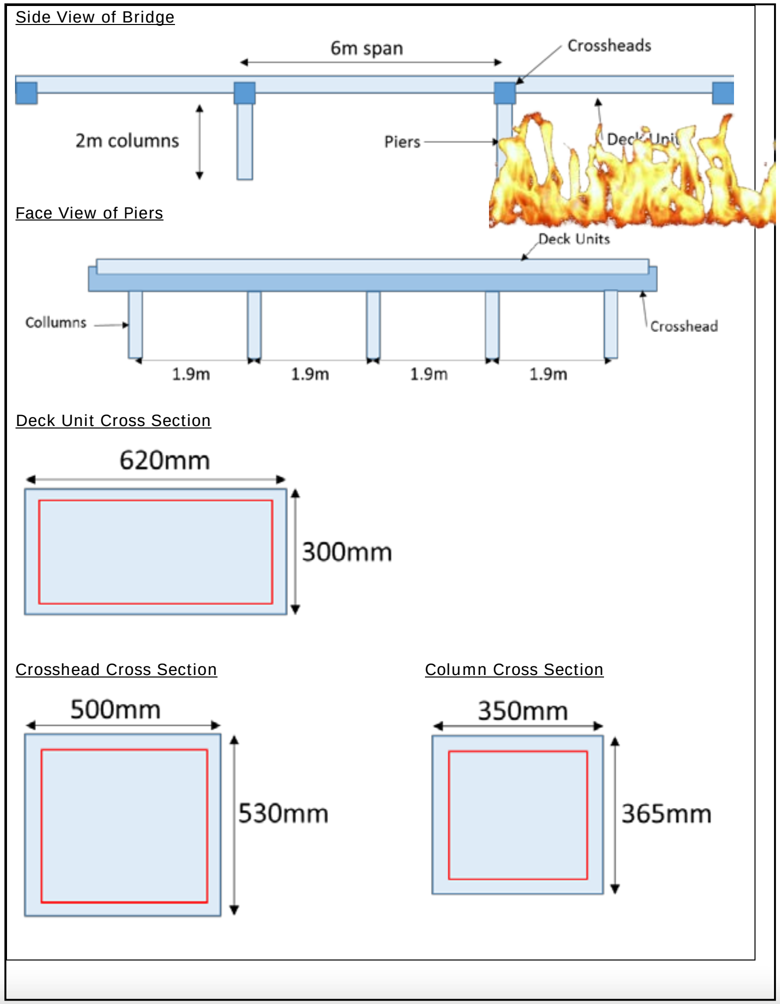
Timber

- Charring (charring rate)
- Strength loss
- Elasticity loss

Local failure and global structural integrity

BRIDGES UNDER BUSHFIRE EXPOSURE/OTHER FIRE HAZARDS

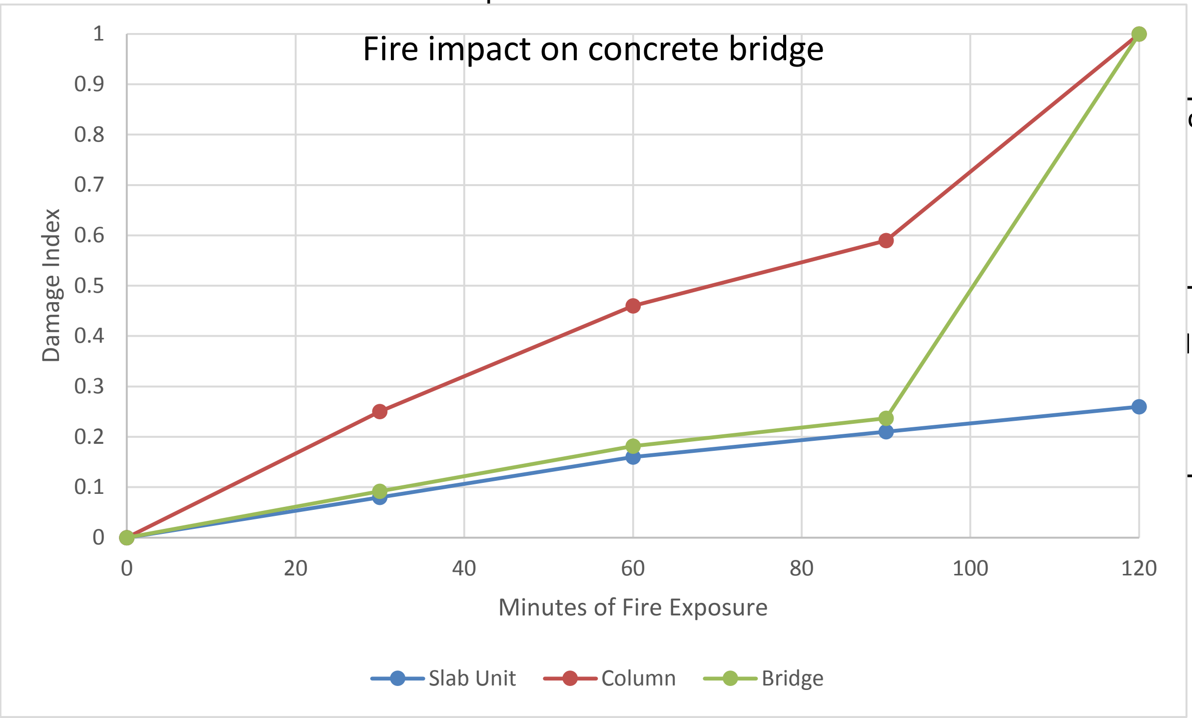
500c Isotherm method



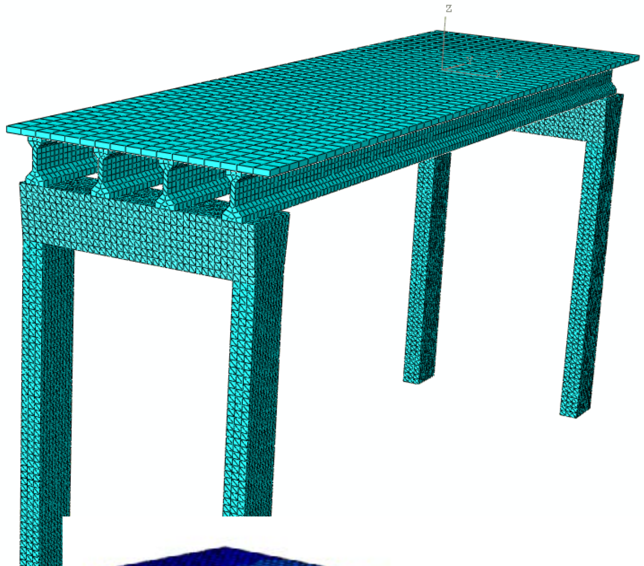
- Constructed in 1964;
- Superstructure consists of 3 spans formed from 14 precast prestressed concrete deck units
- Reinforced concrete cast insitu columns, abutments and crossheads;
- 2 piers (5 piles to a crosshead in each pier);
- 4 piles support each Abutment

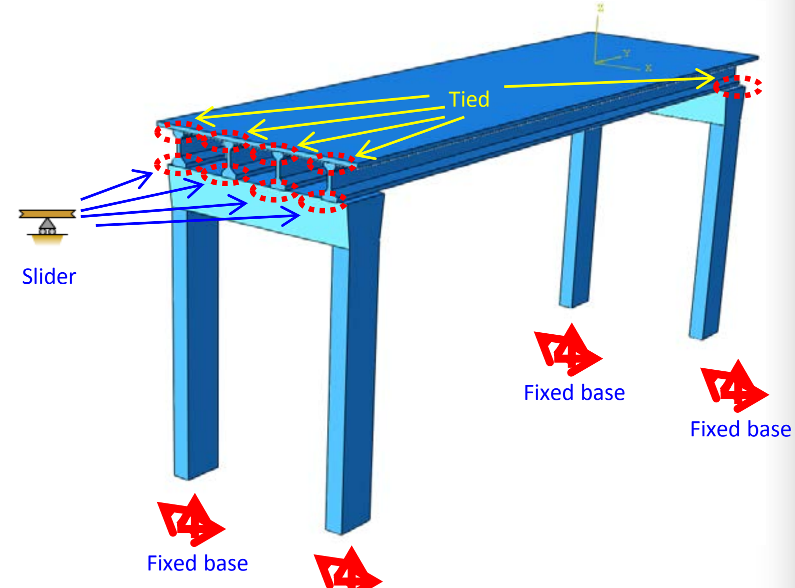
CONCRETE BRIDGE CASE STUDY

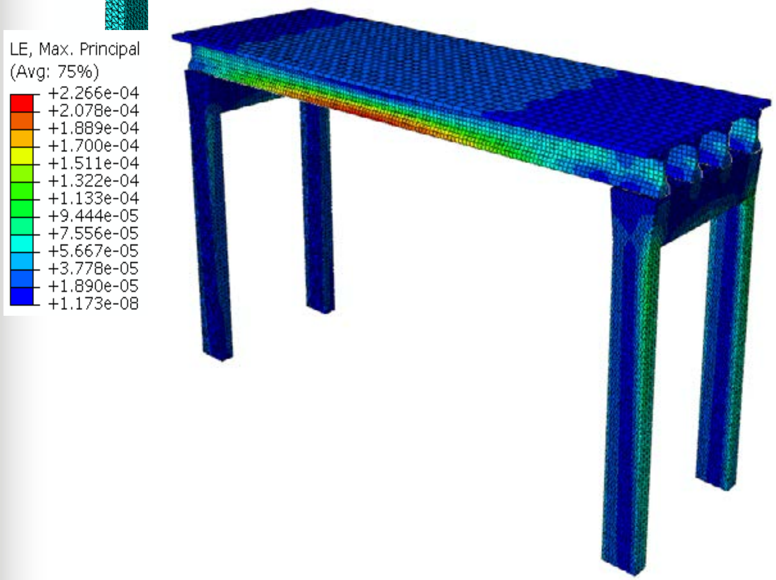
Exposure Time	Deck Units	Columns
30 minutes	Stiffness has dropped by close to 20%. No risk of failure. Small amount of extra damage from deflection likely.	Moment capacity has dropped by 5%, compression capacity has dropped by 13%, and stiffness has dropped by 60%. No risk of failure.
60 minutes	Sagging moment capacity has dropped by 35%, and stiffness by 33%. Failure unlikely. Extra damage from de	Moment capacity has dropped by 29%, compression capacity has dropped by 29%, and stiffness has dropped by 75%.
90 minutes	Sagging moment capa by 42%. Failure unlikely. Extra damage from de	city
120 minutes	Sagging moment capa by 48%. Flexural Failure possib Extra damage from de	l by



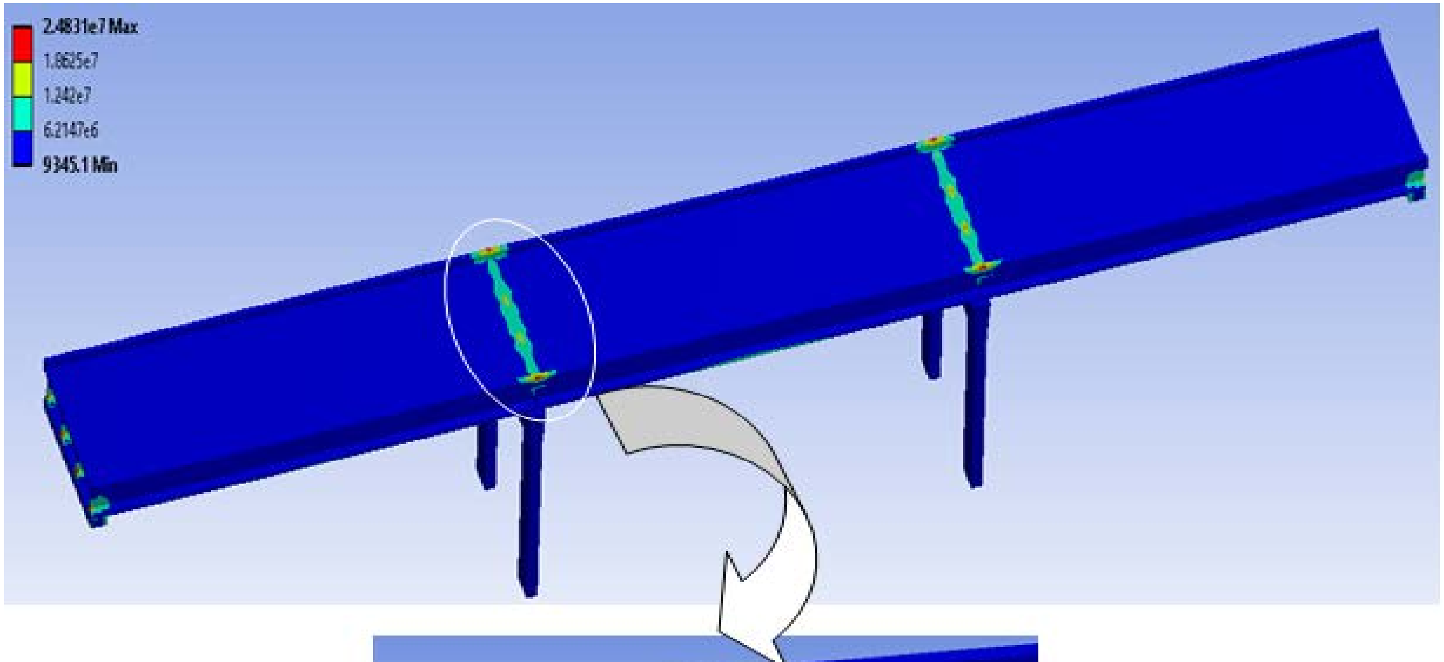
CONCRETE BRIDGE - NUMERICAL ANALYSIS – IN PROGRESS

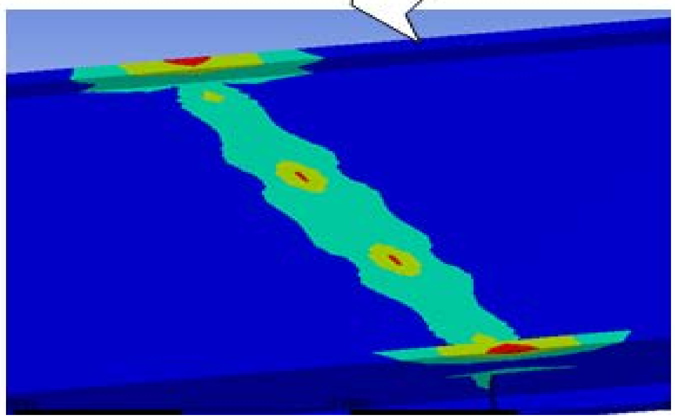




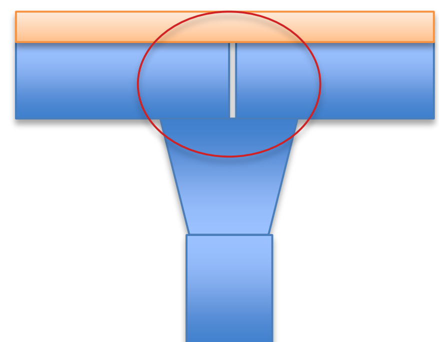


CONCRETE BRIDGE – EARTHQUAKE





Deck Joint failures

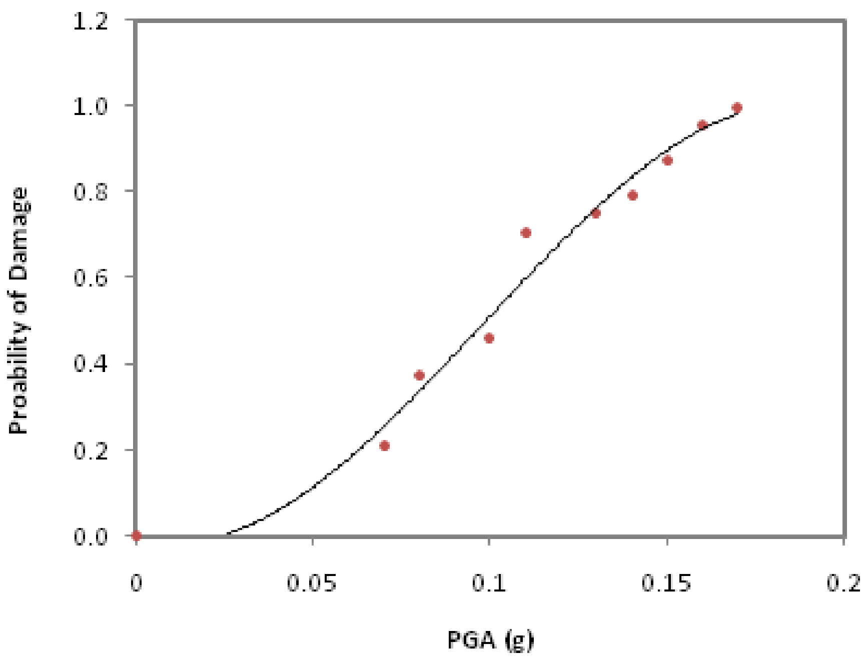


DAMAGE STATES AND CORRESPONDING C/D RATIOS USED IN THE STUDY (HWANG ET AL., 2000)

Damage state	Description	C/D Ratios
No Damage	Minor inelastic response post-earthquake damage -limited to narrow cracking in concrete. No permanent deformations	$\frac{C}{D} \geq 0.5$
Repairable damage	Inelastic response - concrete cracking, reinforcement yield and minor spalling of cover concrete Extent of damage should be sufficiently limited structure can be restored essentially to its pre-earthquake condition without replacement of reinforcement or structural members. Repair should not require closure. Permanent offsets should be avoided.	$0.5 > \frac{C}{D} \geq 0.33$
Significant damage	Permanent offsets may occur Damage consisting of cracking, reinforcement yielding, and major spalling of concrete Require closure to repair Partial or complete replacement may be required in some cases.	$\frac{C}{D} < 0.33$

EARTHQUAKE FRAGILITY CURVES

Damage state	PGA								
	0.07	**0.08**	**0.1**	**0.11**	**0.13**	**0.14**	**0.15**	**0.16**	**0.17**
No Damage	0.208	0.375	0.458	0.708	0.750	0.792	0.875	0.958	1.000



CONSEQUENCE ASSESSMENT

Direct

Intangible

- Loss of lives
- Injuries
- Damage to cultural/asset heritage
- Psychological distress

Tangible

- Damage to road structure
- Damage to vehicles
- Damage to utility systems
- Debris and deposition cleans up cost

Indirect

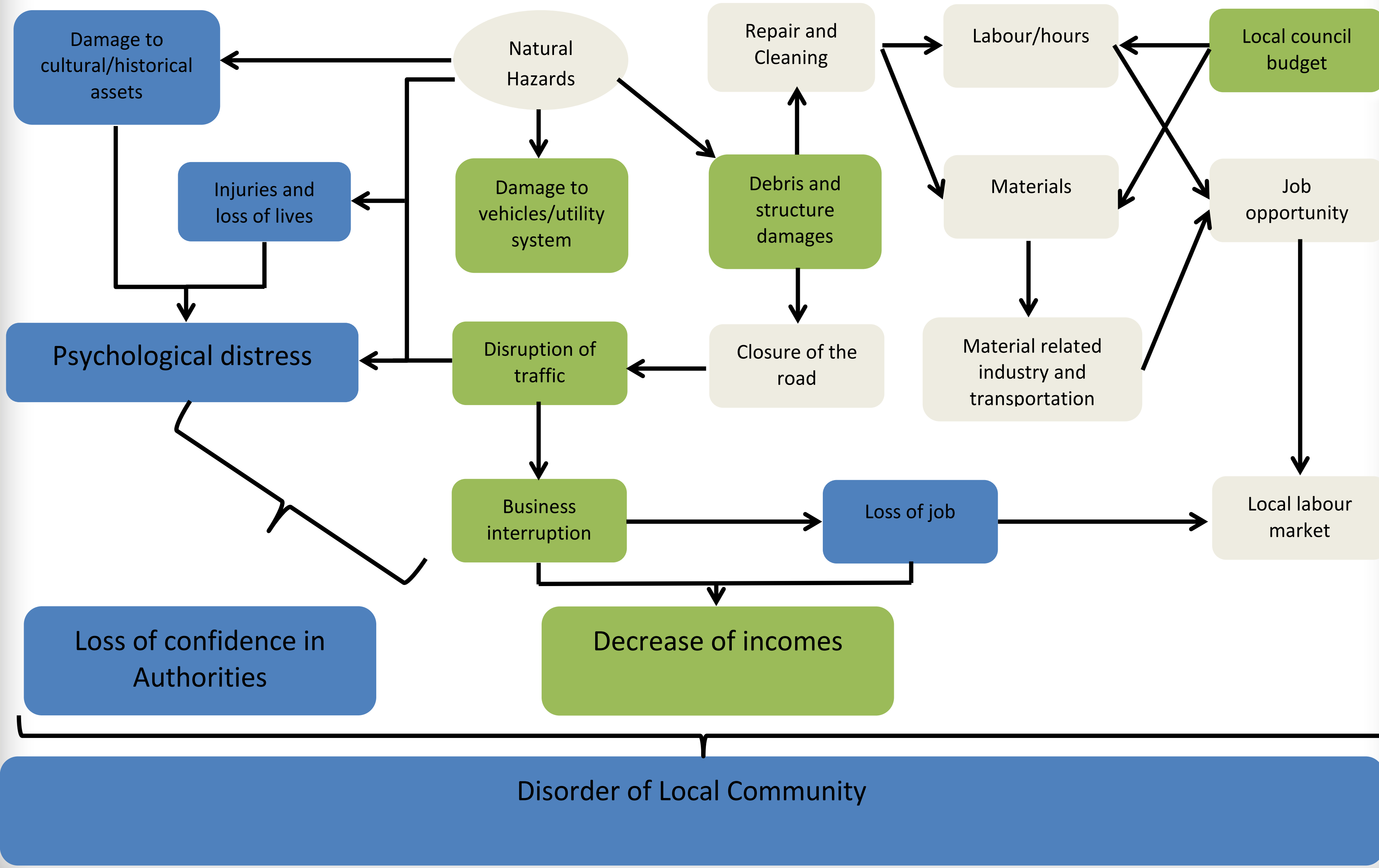
Intangible

- Loss of confidence/ trust in Authorities
- Loss of jobs (Social disruptions)
- Community disorder

Tangible

- Cost of traffic/transport disruption
- Business interruption due to the loss of the road
- Loss of incomes

CAUSE AND EFFECT ANALYSIS



DIRECT TANGIBLE IMPACT

Possible damage to components

Approach

Abutment

Deck

Pile

Pier

Girder

DIRECT TANGIBLE IMPACT DUE TO FLOOD

Depth of Flood — Quarterly submerged, Half submerged, Fully submerged as to the height of the deck.

Velocity — Four level of the velocity of the water: 0-2m/s, 2-4m/s, 4-5m/s, over 5m/s

Depth of Flood + Velocity of Flood =? Damage Extent + Debris Quantity

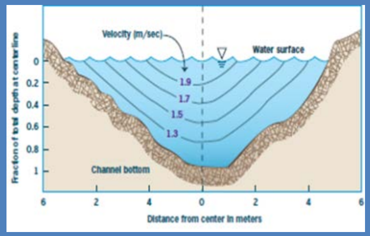
DIRECT TANGIBLE IMPACT

Damage Scenarios

Hazard Scenario

Depth of Flood

- Quarterly submerged
- Half submerged
- Fully submerged



Flow velocity

- 0-2 m/s
- 2-4 m/s
- 4-5 m/
- >5 m/s

Cited from HAL 2005

Vulnerable Component

- Abutment
- Approach
- Deck
- Pile
- Pier
- Girder
- Foundation
- Bearing
- Upstream of the bridge (utilities)

Possible Damages

- Lateral or vertical movement of the structure component
- the spall of the concrete surface
- Padding or soil washed away or eroded by torrent
- Build-up of debris on the upstream side of bridge

Inspection report 2014

KAPERNICKS BRIDGE CASE STUDY


City highway
Gatton
Toowoomba
Kapernicks bridge
White Mountain
Lockyer Forest Reserve
Vinegar Hill
Ballard
Upper Lockyer
Lockyer
Lake Clarendon
Adare
Jubilee Park
Mount Lofty
Helidon Spa
Helidon
Blanchview
Warrego Hwy
Placid Hills
Gatton
Lawes
Redwood Park
Derrymore
Iredale
Carpendale
Lower Tenthill
Rangeville
Gatton National Park
Woodlands
Glen Cairn
Glen Lomond Park
Silver Ridge
Flagstone Creek
Upper Tenthill
Blenheim
Ropeley
Stockyard
Mount Whitestone
Preston
Rockmount
Egypt
Laidley Creek West

ROAD CONDITIONS AND NETWORK

Road connected with the damaged bridge

The mostly used city highway

Reasonable alternative road

Poor condition of alternative road

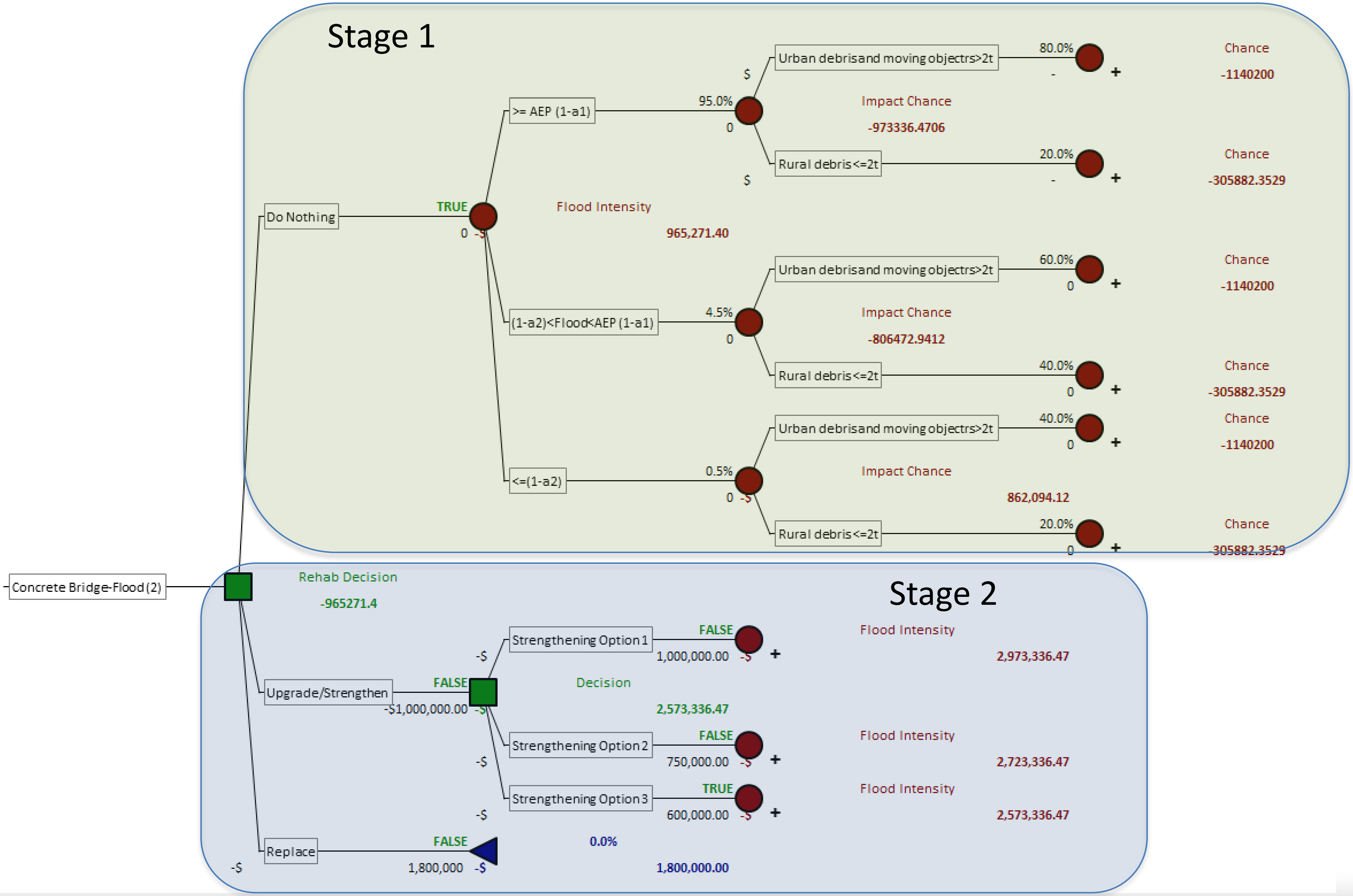
INDIRECT COST ESTIMATION

According to the probabilistic vehicle operating cost model, the vehicle operating cost is from 20 cents/km to 34.5 cents/km, and median operating cost is around 27 cents/km. The median for the heavy vehicle is 50 cents/km
In this case study the average additional travelling distance is around 3.5 km

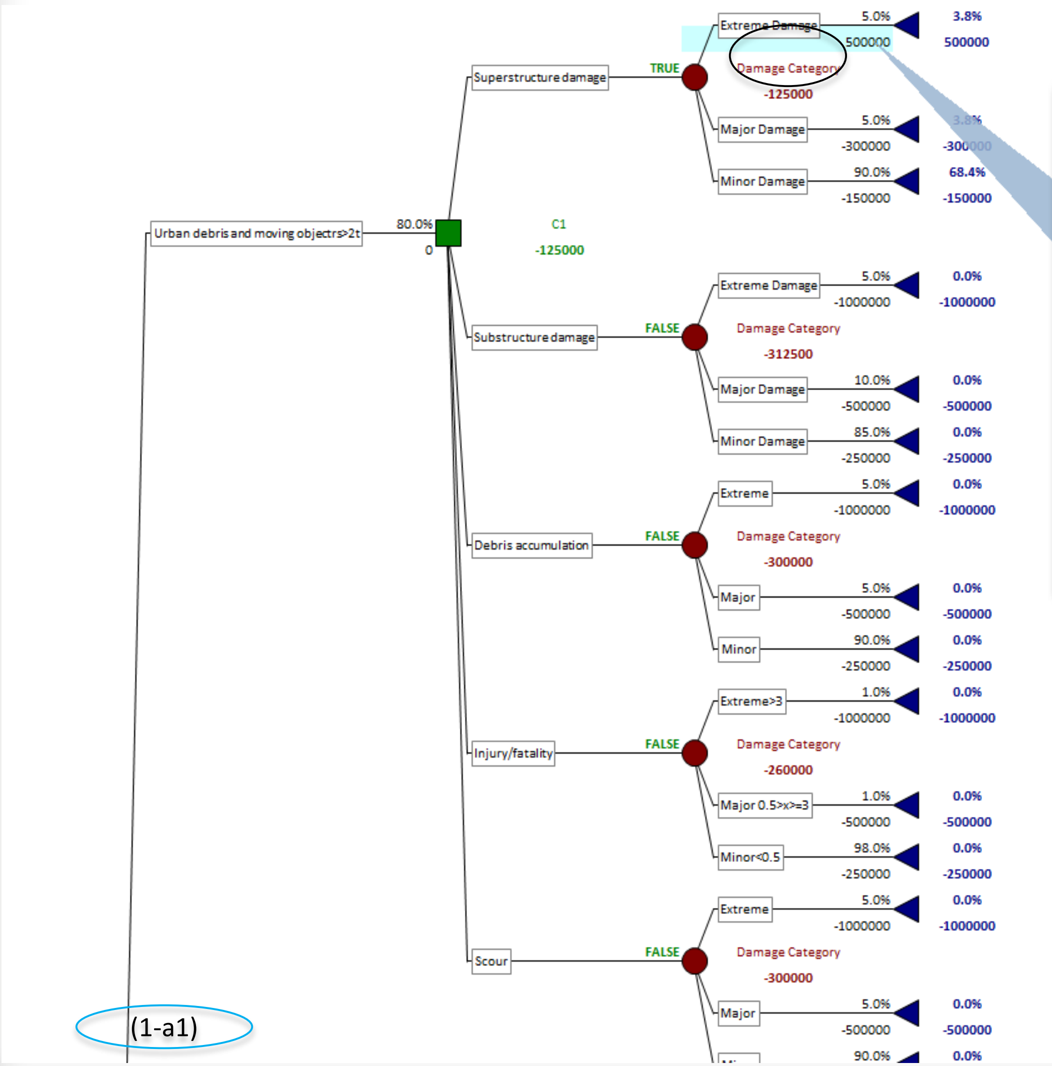
The number of light vehicle is 729*0.745= 544
The number of heavy vehicles is 729*0.255=186
The extra cost for light vehicles estimated at
544*3.5*0.27= $514 per day
The extra cost for heavy vehicles estimated at
186*3.5*0.5= $325 per day.

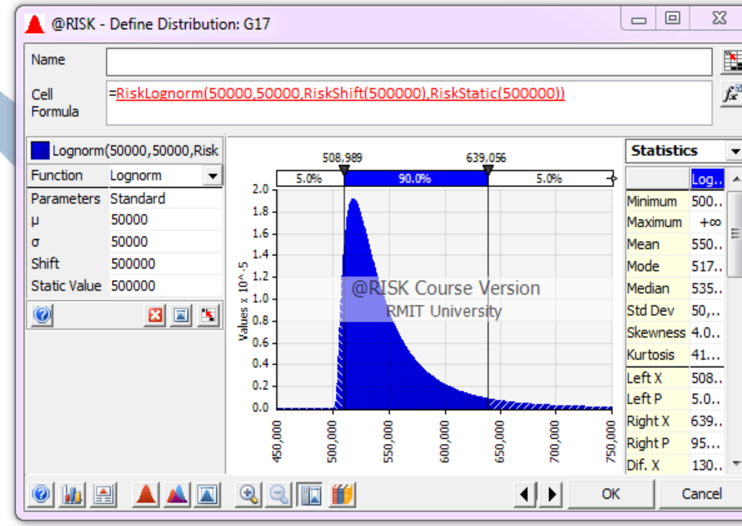
The opportunity loss is mainly the value of the time. The widely used method is to use the average salary to measure the extra travelling time. According to the simulation of the Google map, the median extra time on travel is 8 minutes=0.133h, the average travelers in a vehicle is 1.3. The average salary in the QLD is 20$/h. The opportunity loss of the road users is approximately:
20* 0.133*749*1.3 = $2500 per day

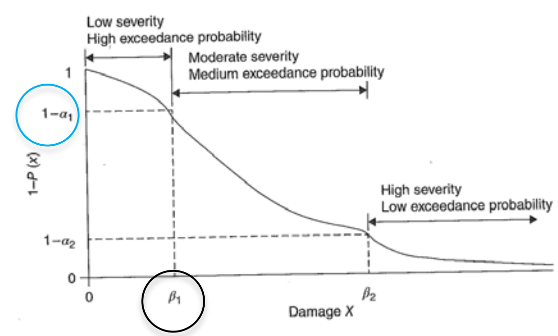
DECISION TREE APPROACH



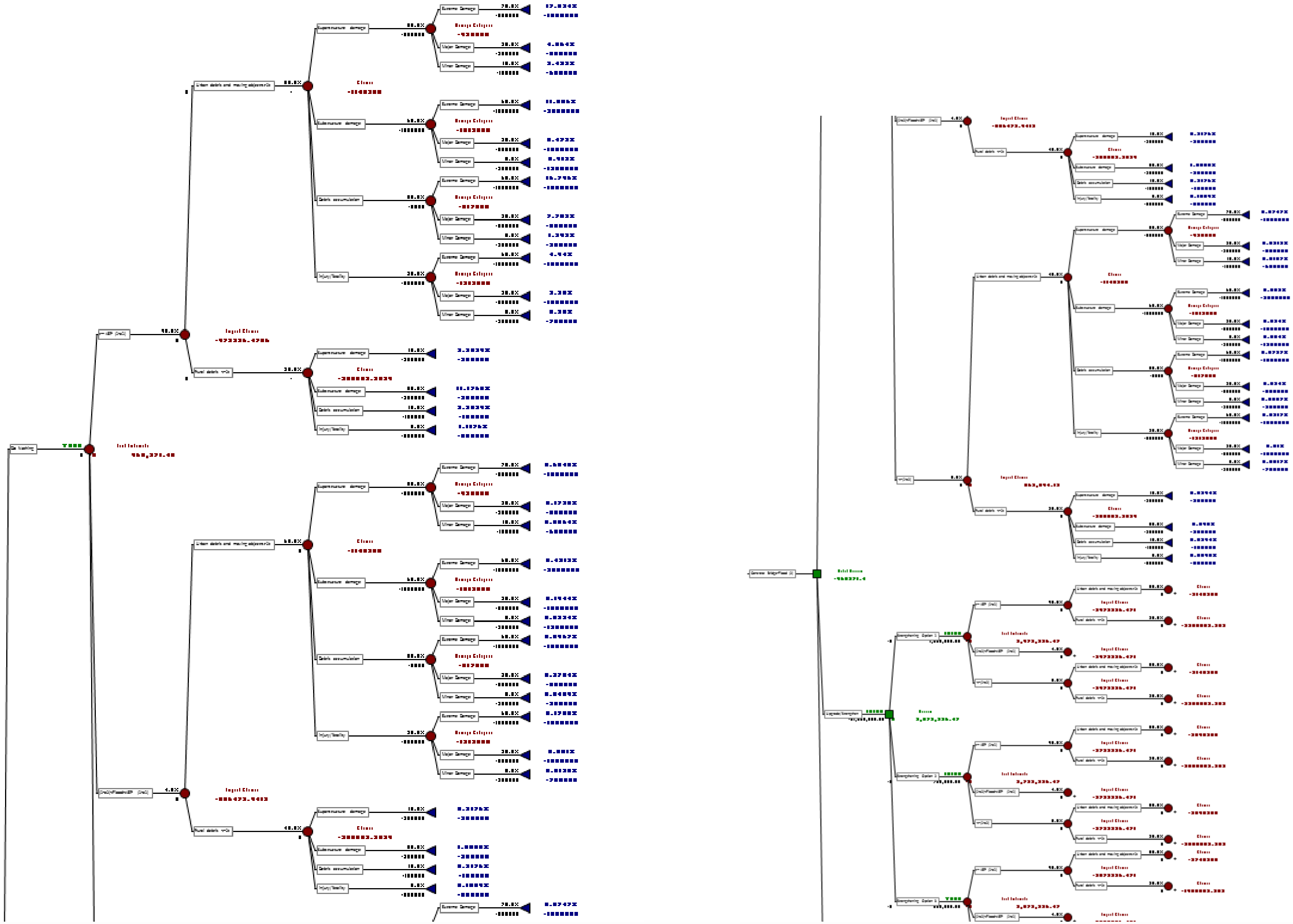
PARTITIONED MULTIOBJECTIVE RISK METHOD (PMRM)







EXTENDED DECISION TREE TO COVER OPTIONS



PLANNED FUTURE ACTIVITIES

- Analysis of design standards and applied loads on road structures under extreme events
- Source further case studies of bridges, varying input data, categorise structures based on obtained vulnerability curves, distribution and reliability
- Gather additional data for deriving damage indices based on cost of recovery
- Further expansion and implementation of the decision support method

UTILISATION-SHORT TERM

- Vulnerability indices developed in the project are used by road authorities and local government to assess resilience of bridges in the case study regions

- Draft design guide for floodways is used by road authorities

TASKS FOR THE RESEARCHERS

- Convert outcomes to user friendly tools – GIS integration

- Provide training for the road authorities and local government bushfire&natural HAZARDSCRC

TANK YOU

QUESTIONS / COMMENTS